Solar Energy 163 (2018) 591–599

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Optimization of solar photovoltaic system integrated with phase change material

Sourav Khanna[a,*], K.S. Reddy[b], Tapas K. Mallick[a,*]

[a] Environment and Sustainability Institute, Penryn Campus, University of Exeter, Cornwall TR10 9FE, United Kingdom
[b] Heat Transfer and Thermal Power Laboratory, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

ARTICLE INFO

Keywords:
Phase change material
Solar photovoltaic
Thermal management
Optimization

ABSTRACT

The rise in the temperature of photovoltaic (PV) leads to decrease in the solar to electricity conversion efficiency. This paper presents a simulated study to investigate the thermal management of the PV panel using phase change material (PCM). It is found that once the PCM is fully melted, the rate of heat extraction by PCM decreases and, thus, the PV temperature starts increasing rapidly. In literature, the studies related to the performance analysis of the PV-PCM system are available. However, the optimization of the PCM quantity to cool the PV in various operating conditions and solar radiation levels is not available. Thus, it has been carried out in the presented work. The effects of the operating conditions (wind azimuth angle i.e. wind direction, wind velocity, melting temperature of PCM and ambient temperature) on the optimum depth of the PCM container have been analysed. The results show that as wind azimuth angle increases from 0° to 90°, the optimum depth of the PCM container (to maintain the PV at lower temperature) increases from 3.9 cm to 5.3 cm for $\Sigma I_T = 5\,\text{kWh/m}^2$/day and from 2.4 cm to 3.2 cm for $\Sigma I_T = 3\,\text{kWh/m}^2$/day for the chosen parameters.

1. Introduction

The temperature of the photovoltaic (PV) cell rises during its operation which reduces its solar to electricity conversion efficiency (Khanna et al., 2017a). The studies that analyse the thermal management of the PV by extracting the heat using phase change material (PCM) have been reviewed. Some studies have been reported that carried out the experimental analysis which are as follows: Huang et al. (2006a) have investigated the performance of the PV-PCM (mimicked PV) system for two cases (with and without fins). It has beenfound that the temperature rise of the front surface can be reduced by 10 °C using fins at an insolation of 750 W/m^2 and an ambient temperature of 23 °C. Straight fins, wire matrix and strip matrix are used to enhance the heat transfer. Hasan et al. (2015) have analysed the PV-PCM system under two different weather conditions (Dublin and Vehari) and found that for Dublin, the maximum temperature reduction in PV is 10 °C at an insolation of 970 W/m^2 and an ambient temperature of 24 °C and for Vehari, it is 21.5 °C at an insolation of 950 W/m^2 and an ambient temperature of 32 °C. Researchers have used different types of PCMs. A yellow petroleum jelly has been proposed by Indartono et al. (2014) and a decrease in the PV temperature from 60 °C to 54.3 °C has been reported for a PV-on-roof system at an insolation of 1120 W/m^2 and an ambient temperature of 25 °C and from 44.8 °C to 42.2 °C for PV-on-stand system. Hasan et al. (2010) have analysed five different PCMs. At solar flux of 1000 W/m^2 and an ambient temperature of 20 °C, a maximum reduction of 18 °C in the PV temperature has been reported. Sharma et al. (2016) have coupled the PCM with a building integrated concentrated PV (BICPV) which resulted in increase of 1.15%, 4.20% and 7.7% in the electrical efficiency at insolation of 500 W/m^2, 750 W/m^2 and 1000 W/m^2 respectively. Huang et al. (2011) have reported the crystalline segregation of the PCM. It has been concluded that the deployment of the internal fins enhances the system's performance. Waksol A, RT27 and RT35 are used for the study at an insolation of 750 W/m^2 and an ambient temperature of 19 °C. Browne et al. (2015b, 2016) have used a pipe network inside the PCM container to utilize the stored heat by flowing water through the pipes which has led to a thermal efficiency of 20–25% at Dublin for three consecutive days in July having an insolation of 950 W/m^2 and an ambient temperature of 20 °C around noon. An increase of 6 °C in the water temperature has been reported against the case when the PV-Thermal system is used without PCM. Some review studies (Du et al., 2013; Browne et al., 2015a; Ma et al., 2015; Shukla et al., 2017) are also reported focusing the thermal performance of the PV-PCM system.

Apart from the experimental studies, there have been several numerical studies for one, two and three-dimensional thermal analysis of the PV-PCM system. The following investigations have carried out the

* Corresponding authors.
E-mail addresses: s.khanna@exeter.ac.uk (S. Khanna), t.k.mallick@exeter.ac.uk (T.K. Mallick).

https://doi.org/10.1016/j.solener.2018.01.002
Received 16 March 2017; Received in revised form 15 December 2017; Accepted 1 January 2018
0038-092X/ © 2018 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/BY/4.0/).

Nomenclature

a_i	coefficient appeared in Eq. (29)
B	liquid fraction of PCM
C_p	specific heat capacity (J/kg K)
D	Dirac delta function
F	view factor between surfaces
g	acceleration due to gravity (m^2/s)
G	heat generation (W/m^3)
Gr	Grashof number
h	convective heat transfer coefficient ($W/m^2 K$)
I_T	solar radiation on tilted surface (W/m^2)
k	thermal conductivity (W/m K)
L	length of the system (m)
L_{ch}	characteristic length (m)
L_h	latent heat (J/kg)
p	pressure (Pa)
Pr	Prandtl number of air
Q_L	rate of heat loss from the top surface (W/m^2)
Re	Reynolds number
S_h	solar radiation converted into heat in the system (W/m^2)
t	time (s)
T	temperature (K)
T_m	peak melting temperature of PCM (K)
u	velocity of melted PCM (m/s)
v_w	wind velocity (m/s)

Greek symbols

β	tilt angle of the panel (rad)
β_c	thermal expansion coefficient of PCM (/K)
γ	wind azimuth angle i.e. the angle made by wind stream with the projection of surface normal on horizontal plane (rad)
δ	depth of PCM container (m)
ΔT	phase change zone (K)
ε	emissivity for long wavelength radiation
$\eta_{PV\ module}$	solar radiation to electricity conversion efficiency of PV module
μ	dynamic viscosity of air (kg/ms)
ν	kinematic viscosity of air (m^2/s)
ρ	density (kg/m^3)
ρ_{PV}	reflectivity of the top surface of the PV module
σ	Stefan–Boltzmann constant ($W/m^2 K^4$)

Abbreviation

BICPV	building integrated concentrated PV
EVA	ethylene vinyl acetate
PCM	phase change material
PV	photovoltaic

Subscripts

a	ambient
c	critical
for	forced convection
g	ground
l	liquid phase
nat	natural convection
P	PCM
s	sky; solid phase
t	top surface
x	x direction
y	y direction

one-dimensional analysis considering the conductive energy flow alone inside the PCM. Brano et al. (2014) have reported a finite difference method for analysing the PV-PCM system which maintains the relative average mismatch between the calculated and the measured values of the PV temperature below 7% for summers in Palermo having an insolation of 1000 W/m^2 and an ambient temperature of 25 °C around noon. Atkin and Farid (2015) have analysed four systems: (A) only-PV, (B) PV-PCM, (C) PV-Heatsink and (D) PV-PCM-Heatsink and found an electricity enhancement of 7.32%, 11.70% and 12.97% using systems B, C and D respectively as compared to system A. Smith et al. (2014) have calculated the electricity generation by PV-PCM system for countries all over the world and the performance in the tropical regions are found to be the best. An increase of over 6% in the electricity output has been reported for Mexico and Eastern Africa. Mahamudul et al. (2016) have studied the behaviour of the PV-PCM system and found a reduction of 10 °C in the PV temperature for a period of 6 h using RT 35 PCM under Malaysian climate having maximum insolation of 1000 W/m^2 and an ambient temperature of 35 °C. Kibria et al. (2016) have analysed three different PCMs and found a 5% increment in the PV efficiency at an insolation of 750 W/m^2 and an ambient temperature of 20 °C. It is also found that for 8 h of operation, RT20 gets fully melted whereas RT25 and RT28HC gets melted up to 80% and 65% respectively. Park et al. (2014) have studied the performance of the PV-PCM system by varying the melting temperature and the thickness of the PCM layer. It is found that the PV temperature can be reduced by 10 °C using 100 mm thick PCM layer at an insolation of 780 W/m^2 and an ambient temperature of 19 °C. Aelenei et al. (2014) have achieved a thermal efficiency of 10% and an overall (electrical + thermal) efficiency of 20% in a building integrated PV-PCM system at Lisbon for a day having an insolation of around 900 W/m^2 and an ambient temperature of 12 °C at noon. Elarga et al. (2016) have analysed the performance of the PV-PCM system integrated in double skin facades and found a reduction of 20–30% in the monthly energy demand for cooling and an increment of 5–8% in the electricity generation. The locations considered for the study are Venice, Helsinki and Abu Dhabi. The reduction in the heating load in cold-dominated locations is found to be limited.

Despite above studies, it is a fact that the energy flow due to convection inside the melted PCM affects the system's performance significantly (Kant et al., 2016). The following numerical studies have considered it and the side walls of the PCM container are considered to be insulated which leads to the temperature variations along the height and the thickness of the system. Thus, the following studies have carried out the two-dimensional thermal analysis. Huang et al. (2004) have studied the PV-PCM (mimicked PV) system with and without fins at an insolation of 1000 W/m^2 and an ambient temperature of 20 °C. The temperature of the front surface of the system has been reported to be reduced by 3 °C using fins. It is found that the PCM (melting temperature 32 °C) container having depth of 20 mm can maintain the front surface temperature under 36.4 °C for 80 min. Ho et al. (2012) have reported an increase in the PV electrical efficiency from 19.1% to 19.5% at an insolation of 650 W/m^2 and an ambient temperature of 30 °C and from 17.86% to 17.99% at an insolation of 450 W/m^2 and an ambient temperature of 20 °C using the microencapsulated PCM having melting temperature of 26 °C and depth to length ratio of PCM container as 0.277. Huang (2011) has studied the use of two different PCMs in a same container at an insolation of 1000 W/m^2 and an ambient temperature of 20 °C. RT27-RT27, RT27-RT21 and RT31-RT27 PCMs have been chosen and RT27-RT21 combination is found to be the best. Khanna et al. (2017b) have studied the effect of tilt angle of the PV-PCM system on the melting rate of the PCM and found that as tilt

Download English Version:

https://daneshyari.com/en/article/7935604

Download Persian Version:

https://daneshyari.com/article/7935604

Daneshyari.com